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Quantitative analysis of the impact of droughts and floods on internal wars in China over the last 500 years

Harry F. LEE[1*], David D. ZHANG[1,2], PEI Qing[3], JIA Xin[4] & Ricci P. H. YUE[1]

[1] *Department of Geography and International Center for China Development Studies, The University of Hong Kong, Hong Kong, China;*
[2] *School of Geographical Sciences, Guangzhou University, Guangzhou 510006, China;*
[3] *Department of Social Sciences, The Education University of Hong Kong, Hong Kong, China;*
[4] *School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing, 210023, China*

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Abstract Although many large-N quantitative studies have evidenced the adverse effects of climatic extremes on social stability in China during the historical period, most of them rely on temperature and precipitation as major explanatory variables, while the influence of floods and droughts on social crises is rarely measured. Furthermore, a comparison of the climate-society nexus among different geographic regions and at different temporal scales is missing in those studies. To address this knowledge gap, this study examines quantitatively the influence of floods and droughts on internal wars in three agro-ecological (rice, wheat, and pastoral) regions in China in AD1470–1911. Poisson regression and wavelet transform coherence analyses are applied to allow for the non-linear and non-stationary nature of the climate-war nexus. Results show that floods and droughts are significant in driving internal wars in historical China, but are characterized by strong regional variation. In the rice region, floods trigger internal wars at the inter-annual and multi-decadal time scales. In the wheat region, both floods and droughts cause internal wars at the inter-annual and multi-decadal time scales. In the pastoral region, internal wars are associated with floods only at the multi-decadal time scale. In addition, the multi-decadal coherence between hydro-climatic extremes and internal wars in all three of the agro-ecological regions is only significant in periods in which population density is increasing or the upper limit of regional carrying capacity is being reached. The above results imply that the climate-war nexus is mediated by regional geographic factors such as physical environmental setting and population pressure. Hence, we encourage researchers who study the historical human-climate relationship to boil down data according to geographic regions in the course of statistical analysis and to examine each region individually in follow-up studies.

Keywords Floods and droughts, Climatic extremes, Internal wars, Wars, Social stability, Ming-Qing period

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1. Introduction

In recent years, there have been an increasing number of large-N studies examining quantitatively the influence of climate change on various aspects of human societies in China during the historical period. The aspects covered include agricultural production (Yin et al., 2015), economic fluctuations (Wei et al., 2014, 2015a, 2015b; Yin et al., 2015; Pei et al., 2016b), armed conflicts (Zhang et al., 2007; Zhang and Lee, 2010; Zhang et al., 2010; Jia, 2014), epidemics (Pei et al., 2015b; Lee et al., 2017), migrations (Pei and Zhang, 2014; Pei et al., 2016a), geo-politics (Bai and Kung, 2011; Zhang et al., 2015), population growth dynamics (Lee et al., 2008, 2009; Lee and Zhang, 2010b, 2013; Lee, 2014; Lee

* Corresponding author (email: harrylee@hku.hk)

et al., 2016b), and dynastic cycles (Zhang et al., 2005, 2006; Yin et al., 2016a, 2016b; Li J et al., 2017). Based on various statistical methods and research materials, scholars generally conclude that there have been more frequent and severe socio-economic, political, and demographic crises in a deteriorating climate (i.e., cold and dry) throughout Chinese history. The deficiency of heat energy and precipitation, as well as the increasing number of meteorological disasters, result in agricultural shrinkage. The shrinkage interacts with rapid population growth to engender food shortage, and consequently, socio-economic and political instability and ultimately population collapse (Lee and Zhang, 2010b, 2013; Lee, 2014).

The above studies provide scientific evidence via statistical means about the adverse societal effects generated by climate deterioration, shedding light on the role of climate change in shaping Chinese history in a macro perspective. Nevertheless, those studies mainly rely on temperature and precipitation as major explanatory variables, while the influence of hydro-climatic extremes (i.e., floods and droughts), which is also among the major climatic variables, on social crises is only quantified in a few large-N studies (Zhang et al., 2010; Jia, 2014). In addition, the comparison of the climate-society nexus among different geographic regions and at different temporal scales is missing in those studies. Floods and droughts are two of the major natural disasters affecting crop production in historical China and are even more imperative than extremely high temperature and extremely low temperature in distorting the long-term equilibrium of food production (Liu et al., 2012). In ancient China, the detrimental effect of floods and droughts on agricultural production may lead to internal wars (Zhang et al., 2009, 2010). Given that internal war is an important indicator of social instability in ancient China (Jia, 2014), this study examines quantitatively the influence of hydro-climatic extremes, namely floods and droughts, on internal wars in different agro-ecological regions in China at different temporal scales to supplement the existing quantitative analysis of the climate-society nexus in Chinese history. If the hydro-climatic extremes are found to be significant in causing internal wars, we will proceed to examine whether floods or droughts play a more important part.

2. Data and methods

2.1 Study period and study area

The study period is delimited to AD1470–1911 (the late Imperial era, which spans the Ming (c. AD1368–1644) and Qing (c. AD1644–1911) dynasties), a period commonly covered in our datasets (cf. Section 2.2). Regarding the study area, although the territory of China has changed from time to time, the cycles of man-land relationship in Chinese history are basically consistent (Lee and Zhang, 2010b, 2013; Lee, 2014). Hence, the current Chinese territory is delimited as the study area. As the human-land relationship in historical societies is characterized through changes in agricultural production, China is further divided into three agro-ecological zones according to the general zonation of Chinese agricultural geography (Pei and Zhang, 2014; Pei et al., 2016a), namely rice, wheat, and pastoral regions (Zhao, 1986) (Figure 1). Such delineation helps to reveal regional variation in the influence

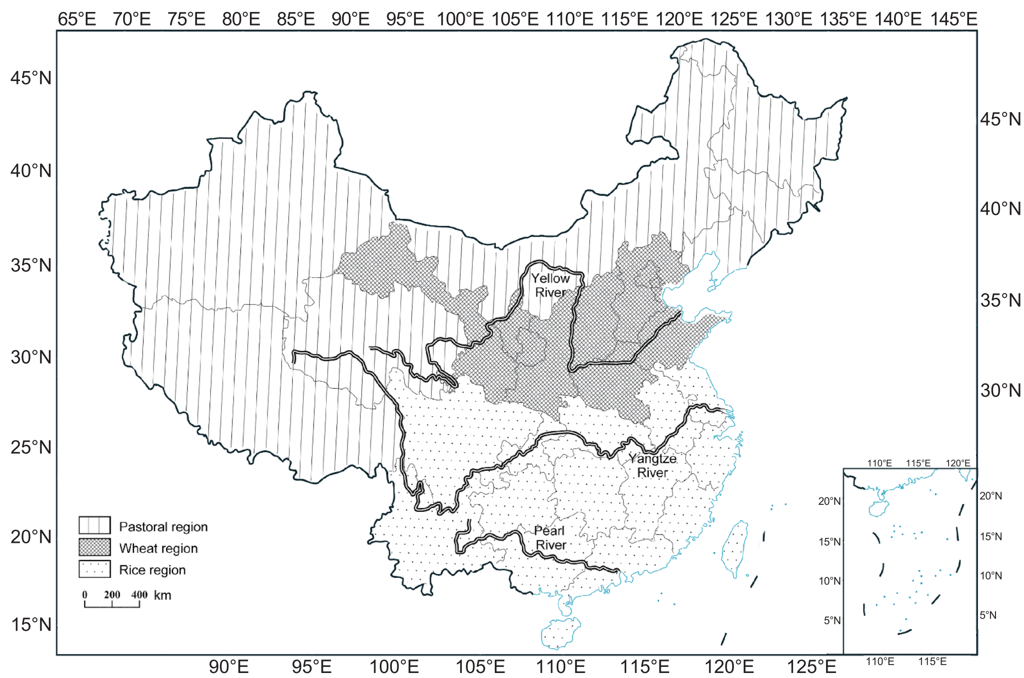

Figure 1 Rice, wheat, and pastoral regions in China.

of hydro-climatic extremes on internal wars, if any. The Yangtze River is the major physical divide in China: the region south of the river is rice-cultivated area, while the region north of the river is wheat-cultivated area (Talhelm et al., 2014). Xinjiang, Inner Mongolia, and the Tibet Plateau are the traditional pastoral regions in China. Northeastern China was occupied by nomads. Though part of northeastern China is suitable for farming, it has never been a major agricultural zone throughout Chinese history (Cosmo, 1994). Therefore, northeastern China is merged with Xinjiang, Inner Mongolia, and Tibet to form the pastoral region (Zhao, 1986).

2.2 Data

To guarantee data reliability, only those data that are confirmed by scholars in their research are employed in this study. Their details are stated below:

The data for hydro-climatic extremes are primarily derived from the *Yearly Charts of Dryness/Wetness in China for the Last 500-year Period* (Chinese National Meteorological Administration, 1981), which contains dryness/wetness grade series for 120 sites in China in AD1470–1979. In recent years, Bai et al. (2010) have updated the dryness/wetness grade series of the 12 sites and added the dryness/wetness grade series of 7 new sites in northwestern China, and those data are published in the *Yearly Charts of Dryness/Wetness in NW China for the Last 500-year Period* (AD1470–2008). These two yearly charts are merged and then employed for the identification of floods and droughts in this study. In the above yearly charts, a 5-point grading system is applied to describe local climatic conditions, ranging from extremely wet to extremely dry (1 to 5). The dryness/wetness grades of each site in AD1470–1950 (i.e. the period without instrumental precipitation records) are assigned according to the statistical evaluation of historical descriptions about dry/wet conditions in local gazettes and other historical documents, while the grades in AD1951–2008 (i.e. the period with instrumental precipitation records) are assigned according to the measured amounts of summer (May–September) rainfall at the meteorological stations nearby. The quantification of flood and drought is done by counting the number of sites that have data in any given year whose dryness/wetness grade is 1 (i.e. extremely wet=flood) and 5 (extremely dry=drought) in the rice (Figure 2a and d), wheat (Figure 2b and e), and pastoral regions (Figure 2c and f), respectively.

As regards internal wars, our data came from a multi-volume compendium *Tabulation of Wars in Ancient China*, which exhaustively records information on the wars that took place in China from 800 BC to AD 1911 (Editorial Committee of Chinese Military History, 1985). Based on the types of participants, particularly leaders of the two sides in the armed conflicts, wars are further put into two categories, namely nomadic invasions and internal wars. In this study, only internal wars are considered (cf. Section 1), and are counted in terms of the number of battles in the rice (Figure 2g), wheat (Figure 2h), and pastoral (Figure 2i) regions,

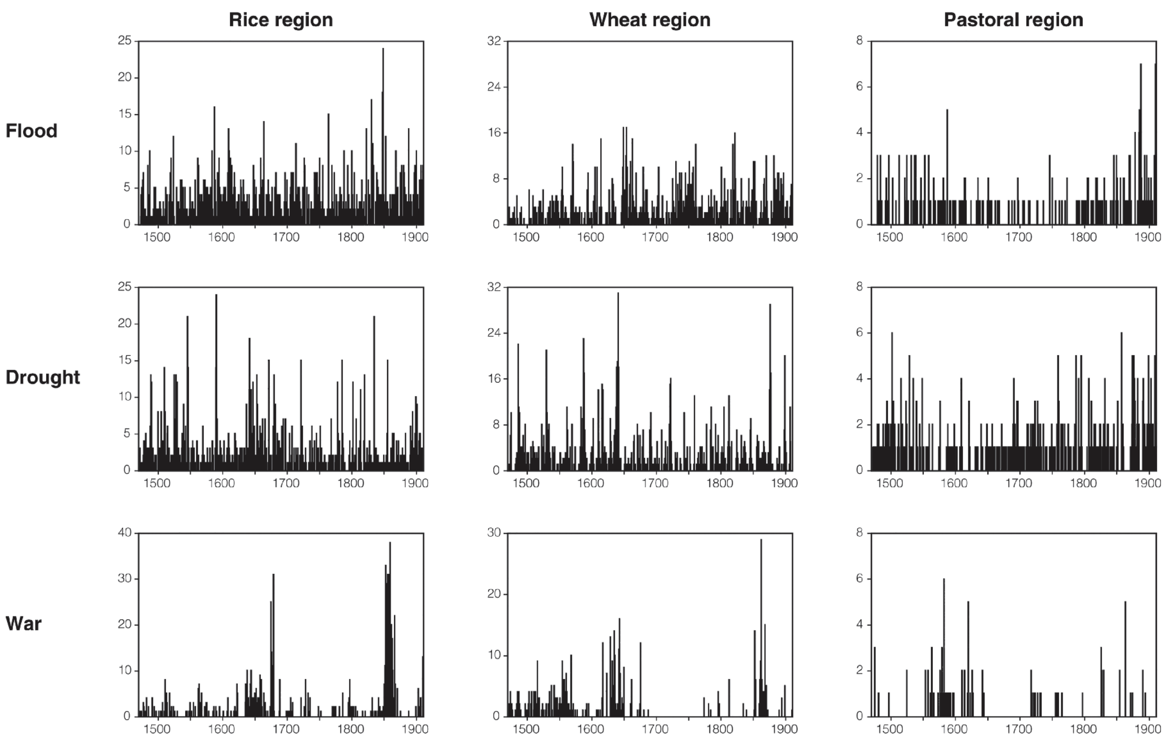

Figure 2 Hydro-climatic extremes and internal wars in the three agro-ecological regions in China in AD1470–1911. Floods in the (a) rice, (b) wheat, and (c) pastoral regions. Droughts in the (d) rice, (e) wheat, and (f) pastoral regions. Internal wars in the (g) rice, (h) wheat, and (i) pastoral regions.

respectively.

For population, the historical population size data are retrieved within the current political boundaries of China from Zhao and Xie's (1988) Chinese provincial population dataset, which is published in *Chinese Population History*. The dataset contains provincial population estimates in China spanned AD2–1983. As Zhao and Xie (1988) give estimates of Chinese population size at irregular time intervals, the common logarithm of the data points is taken, linearly interpolated and then anti-logged back to create an annual time-series. This method avoids distortions of the population growth rate in data interpolation, which has also been applied in previous studies (Lee et al., 2008, 2009). The population data are then divided by the area of associated geographic units to obtain population density figures in the rice, wheat, and pastoral regions, respectively (Pei et al., 2016a).

2.3 Statistical methods

The link from climate to socio-economic crises can be summarized as follows: deteriorating climate causes poor harvest, followed by economic hardship, and eventually wars, famines, and epidemics (Zhang et al., 2011). However, agricultural production and food price are affected by climate variation (Pei et al., 2013, 2014, 2015a, 2016b). Wars happen if such food strain cannot be resolved. The inclusion of agricultural production and food price as control variables may (1) incorrectly absorb the signal contained in our concerned climate variable; and (2) result in a biased estimate because populations differ in unobserved ways and become artificially correlated with climate (Hsiang et al., 2013). Therefore, the statistical analyses in this work are primarily based on the hydro-climatic extremes and internal wars variables.

Traditional statistical methods are grounded on the assumption that the statistical properties of time-series are linear and do not vary with time. Nevertheless, the human-land relationship is highly complex in nature. Climate change affects human societies through a variety of pathways. Agro-ecology is the first to be affected, then the economy and human ecology (Lee et al., 2015b, 2016a, 2016b; Pei et al., 2016a; Lee et al., 2017). Climate change can have both long-term and short-term impacts on human societies, although their associated mechanisms are not exactly identical (Zhang et al., 2011). On one hand, even if climate change can cause the shortage of subsistence, human societies will be significantly affected only if the shortage reaches a certain threshold. The associated social impacts can be drastic and sudden (Lee, 2014). On the other hand, as human societies have always been developing and transforming, we cannot assume the climate-society nexus to be constant over time (Lee et al., 2015b). Therefore, in the temporal dimension, the association between climate change and human societies could be "non-linear" and "non-stationary". The application of traditional statistical methods (e.g., linear regression) in examining the climate-society nexus may be problematic. Therefore, Poisson regression and wavelet transform coherence analyses are applied to examine the relationship between hydro-climatic extremes and internal wars in this study.

Poisson regression is designed using the format of a logarithm model (Brouhns et al., 2002), which is one of the most suitable methods for handling count data (Cameron and Trivedi, 1998). Such method has been applied to scrutinize the association between climate change and epidemics in historical China (Pei et al., 2015b). In this study, we employ Poisson regression analysis to examine the inter-annual association between hydro-climatic extremes and internal wars in the three agro-ecological regions in China. In Poisson regression models, the frequency of internal wars is entered as a dependent variable, with the inter-annual change (i.e. the proportional change since the previous year) of floods (*flood* and $flood_{t-1}$) and droughts (*drought* and $drought_{t-1}$) as explanatory variables (Lee et al., 2013, 2016a), while the frequency of internal wars in the previous two years ($internal\ war_{t-1}$ and $internal\ war_{t-2}$) are entered as explanatory variables to control for auto-correlated errors in the internal war time series (Lee et al., 2013, 2016a). In addition, as a single time series can be characterized by different growth dynamics in different periods, the calendar year and its squared and cubic terms (*year*, $year^2$, and $year^3$) are also included as explanatory variables to control all of the possible time trends of the internal war data (Pei et al., 2015b).

The mechanism of wavelet transform coherency analysis is such that by performing continuous wavelet transformation, the signal in time-series is decomposed into both time and frequency components. Through the calculation of the wavelet power spectrum in the time-frequency domain and the distribution of the variance of the time-series (Grinsted et al., 2004; Cazelles et al., 2008), association between time-series in specific frequency-time domain (periodic cycles) can be identified (Torrence and Compo, 1998; Cazelles et al., 2007, 2008). Such method has been applied to scrutinize the association between climate change and demographic crises in northwestern China in the late Imperial era (Lee et al., 2016b). In this study, we employ multiple wavelet coherence (MWC) and partial wavelet coherence (PWC) analyses (Ng and Chan, 2012) to explore the combined and individual (stand-alone) effect of floods and droughts on internal wars in the three agro-ecological regions in China at multiple time scales. MWC is designated for seeking the wavelet coherence of multiple independents on a dependent, while PWC is used to seek the wavelet coherence between two time-series after eliminating the influence of their common dependence (Ng and Chan, 2012). Morlet wavelet is employed to decompose signals, which is generally regarded as an efficient means of detecting variations in the periodicities of geophysical signals along time-series in a continuous manner (Rigozo et al., 2008).

3. Results

The inter-annual association between hydro-climatic extremes and internal wars in the three agro-ecological regions in China is revealed by Poisson regression results. When the auto-correlated errors in *internal war* time-series are controlled by the inclusion of the variables *internal war*$_{t-1}$ and *internal war*$_{t-2}$ in regression models (Table 1), *flood* is positively associated with *internal war* in the rice region ($p<0.01$). In the wheat region, *internal war* is positively associated with *drought* ($p<0.1$) and *drought*$_{t-1}$ ($p<0.01$). In the pastoral region, *drought* is weakly associated with *internal war* ($p<0.1$), but the effect is negative. On top of the control of the auto-correlated errors, the time trends of the *internal war* data are controlled by the inclusion of the variables *Year*, *Year*^{2}, and *Year*^{3} in regression models (Table 2). It is found that in the rice region, *flood* is still positively correlated with *internal war* ($p<0.01$). In the wheat and pastoral regions, however, the results change a bit, implying that the inter-annual association between hydro-climatic extremes and internal wars in those regions may be mediated by the time trends of the *internal war* data. In the wheat region, *internal war* is positively correlated with *flood* ($p<0.1$), *flood*$_{t-1}$ ($p<0.05$), and *drought*$_{t-1}$ ($p<0.01$). Also, the variable *drought* is very near to be statistically significant ($p=0.103$). This suggests the inter-annual variability of internal wars in the wheat region to be influenced by the synthesis of floods and droughts. In the pastoral region, neither *flood* nor *drought* is associated with *internal war* at the inter-annual time scale ($p>0.1$).

Pinpointing to the association of periodic cycles between hydro-climatic extremes and internal wars in the three agro-ecological regions in China, wavelet analysis (MWC and PWC) is employed. MWC is applied to investigate the combined effect of *flood* and *drought* on *internal war* in the three agro-ecological regions in China (Figure 3a–c). Results show that despite discontinuous coherence in 2–16 year periodicities prevalent in the panels of the rice (Figure 3a), wheat (Figure 3b), and pastoral (Figure 3c) regions, a few coherence bands are relatively consistent. In the rice region, there is a coherence band of 64 year periodicities in AD1725–1911 (Figure 3a). In the wheat region, there is a coherence of 32–64 year periodicities in AD1610–1720 and AD1810–1911 (Figure 3b). And, there is also a coherence band of 128 year periodicities running through almost the entire spectrum (Figure 3c). In the pastoral region, coherence is mainly in the form of 32–64 year periodicities and spans AD1510–1640 and AD1710–1911. The above results suggest that the periodic association between hydro-climatic extremes and internal wars in the three agro-ecological regions is mainly significant at the multi-decadal time scale.

Then, PWC is applied to check the individual effect of *flood* and *drought* on *internal war* in the three agro-ecological regions in China. In the rice region, when the influence of *drought* on *internal war* is controlled, a coherence band in 64 year periodicities between *flood* and *internal war* in AD1725–1911 can be observed (Figure 3d), which is almost identical to the one determined by MWC (Figure 3a). Alter-

Table 1 Estimates of the effect of hydro-climatic extremes on internal wars among different agro-ecological regions in China, with the auto-correlated errors in the internal war time series controlled

	Rice region			Wheat region			Pastoral region		
	Coefficient (SE)	z	Sig.	Coefficient (SE)	z	Sig.	Coefficient (SE)	z	Sig.
Constant	−0.091 (0.085)	−1.07	0.283	−0.548 (0.098)	−5.62	0.000	−1.453 (0.183)	−7.95	0.000
Flood	0.040 (0.012)	3.39	0.001	0.021 (0.016)	1.35	0.176	0.079 (0.103)	0.76	0.445
Flood$_{t-1}$	0.004 (0.012)	0.32	0.752	0.023 (0.016)	1.44	0.150	0.017 (0.112)	0.15	0.878
Drought	−0.001 (0.009)	−0.12	0.902	0.020 (0.011)	1.80	0.072	−0.192 (0.109)	−1.75	0.079
Drought$_{t-1}$	0.013 (0.009)	1.47	0.141	0.046 (0.010)	4.71	0.000	−0.168 (0.109)	−1.54	0.123
Internal war$_{t-1}$	0.067 (0.004)	15.57	0.000	0.103 (0.007)	13.78	0.000	0.273 (0.096)	2.86	0.004
Internal war$_{t-2}$	0.050 (0.004)	11.80	0.000	0.060 (0.010)	5.84	0.000	0.030 (0.142)	0.21	0.833
Observation	440			440			440		
Log likelihood	−1083.124			−849.873			−257.463		
Prob > chi^2	0.000			0.000			0.017		
Pseudo R^2	0.307			0.128			0.029		

Table 2 Estimates of the effect of hydro-climatic extremes on internal wars among different agro-ecological regions in China, with the auto-correlated errors and time trends in the internal war time series controlled

	Rice region			Wheat region			Pastoral region		
	Coefficient (SE)	*z*	Sig.	Coefficient (SE)	*z*	Sig.	Coefficient (SE)	*z*	Sig.
Constant	−479.947 (130.852)	−3.67	0.000	−785.983 (148.721)	−5.28	0.000	−858.908 (354.052)	−2.43	0.015
Flood	0.033 (0.012)	2.76	0.006	0.027 (0.016)	1.74	0.082	0.054 (0.109)	0.49	0.621
Flood$_{t-1}$	−0.001 (0.012)	−0.09	0.926	0.034 (0.016)	2.14	0.032	0.004 (0.118)	0.03	0.974
Drought	−0.002 (0.009)	−0.17	0.869	0.018 (0.011)	1.63	0.103	−0.160 (0.110)	−1.46	0.145
Drought$_{t-1}$	0.012 (0.009)	1.34	0.179	0.042 (0.010)	4.27	0.000	−0.134 (0.109)	−1.23	0.219
Internal war$_{t-1}$	0.065 (0.004)	14.77	0.000	0.108 (0.008)	13.30	0.000	0.231 (0.098)	2.35	0.019
Internal war$_{t-2}$	0.048 (0.004)	11.04	0.000	0.057 (0.011)	5.11	0.000	−0.032 (0.149)	−0.21	0.830
Year	84.968 (23.254)	3.65	0.000	143.012 (26.652)	5.37	0.000	153.448 (63.273)	2.43	0.015
Year^2	−5.003 (1.374)	−3.64	0.000	−8.634 (1.587)	−5.44	0.000	−9.114 (3.759)	−2.42	0.015
Year^3	0.098 (0.027)	3.63	0.000	0.173 (0.031)	5.50	0.000	0.180 (0.074)	2.42	0.016
Observation	440			440			440		
Log likelihood	−1072.794			−810.952			−252.605		
Prob > chi^2	0.000			0.000			0.003		
Pseudo R^2	0.314			0.168			0.047		

natively, when the influence of *flood* is controlled, no continuous coherence band between *drought* and *internal war* can be found (Figure 3g). The above results suggest that internal wars in the rice region in AD1725–1911 are mainly attributable to floods at the multi-decadal time scale. In the wheat region, the PWC results show that the 32–64 year coherence band in AD1610–1720 and AD1810–1911 presented in Figure 3b is neither attributable to *flood* (Figure 3e) nor to *drought* (Figure 3h), implying that the coherence is driven by the synthesis of *flood* and *drought*. The synergistic effect of floods and droughts plays a significant role in triggering internal wars in the wheat region at the multi-decadal time scale. On the other hand, the 128 year coherence band presented in Figure 3b is mainly attributable to *flood* (Figure 3e) rather than *drought* (Figure 3h). Nevertheless, this coherence band is rather affected by the edge effects. Subject to its uncertainty, this coherence band will not be further discussed in this study. In the pastoral region, the PWC results show that the 32–64 year coherence in AD1510–1640 and AD1710–1911, which is presented in Figure 3c, is mainly attributable to *flood* (Figure 3f). Yet, *drought* also contributes significantly to the coherence in AD1710–1911 (Figure 3i).

4. Discussion

Each war incident contains unique elements and features that are impossible to separate and measure across space and time (Buhaug and Rød, 2006). Yet, in a macro-historical perspective, internal wars should be treated as aggregate rather than individual incidents in order to generate statistical rules in history (Pei and Zhang, 2014). This study presents the measurable influence of hydro-climatic extremes on internal wars in Chinese history at the long-temporal and sub-national scales. Also, the relative importance of floods and droughts in causing internal wars in different agro-ecological regions in China is explored. Three pertinent issues are worth discussing here.

4.1 Regional variation

Hydro-climatic extremes are significant in driving internal wars in China in AD1470–1911. Yet, the relationship is characterized by strong regional variation. In the rice region, floods play an important role in triggering internal wars at the inter-annual and multi-decadal time scales. In the wheat

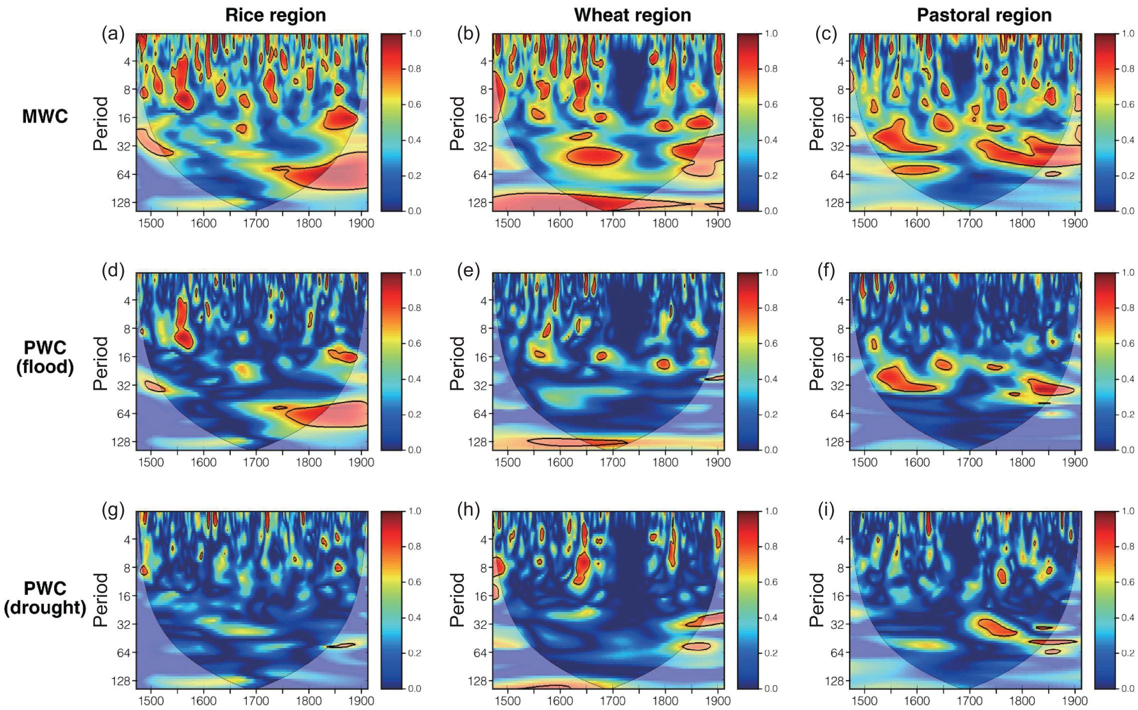

Figure 3 Wavelet transform coherence analysis of hydro-climatic extremes and internal wars in the three agro-ecological regions in China. Multiple wavelet coherence (MWC) analysis of the combined effect of floods and droughts on internal wars in the (a) rice, (b) wheat, and (c) pastoral regions. Partial wavelet coherence (PWC) analysis of the effect of floods on internal wars in the (d) rice, (e) wheat, and (f) pastoral regions, with the effect of droughts controlled. PWC analysis of the effect of floods on internal wars in the (g) rice, (h) wheat, and (i) pastoral regions, with the effect of floods controlled. The black contour indicates significant periodicities (p<0.05) against red noise. The legend indicates coherence values, which vary from dark blue (low values) to dark red (high values). The region outside the cone of influence, where edge effects might distort the picture, is shaded.

region, both floods and droughts are imperative in causing internal wars at the inter-annual and multi-decadal time scales. In the pastoral region, internal wars are associated with floods only at the multi-decadal time scale. Regarding the regional variation about the relationship between hydro-climatic extremes and internal wars, it may be attributable to the diverse physical environment settings among the three agro-ecological regions in China. The rice region is characterized by sub-tropical climate, which is associated with abundant precipitation. Hence, shocks to the agricultural production in the region are associated with floods rather than droughts. On the other hand, the wheat region is associated with semi-arid and semi-humid climate (Zhao, 1986), and part of it is simultaneously influenced by the Westerlies and the East Asian Summer Monsoon (Lee et al., 2015a, 2015c). Such an environmental setting makes the wheat region vulnerable to both floods and droughts. In the pastoral region, the agro-ecological system directly interacts with the physical environment (Pratt et al., 1997), which is highly vulnerable to hydro-climatic extremes (Fang and Liu, 1992; Pei and Zhang, 2014). Compared with agricultural society, pastoral society was more vulnerable to hydro-climatic extremes in the past, owing to its lower level of buffering and technological capacity (Pei and Zhang, 2014; Pei et al., 2016a). However, both floods and droughts are not significant in causing internal wars in the pastoral region at the inter-annual time scale. The explanation may rest on the dominance of nomadic tribes in the region, as well as their migration practices. When there are hydro-climatic extremes, as the associated impacts on the pastoral system are often devastating, nomadic people will migrate southward in search of a place with enough grass and water. This is the only way of adaptation for unsophisticated nomadic tribes during the time (Pei and Zhang, 2014; Pei et al., 2016a). Yet, its direct outcome is the invasion of/migration to the agricultural region (the wheat and the rice region) (Fang and Liu, 1992). In such circumstance, human resources might have been mobilized for nomadic invasions rather than internal wars in the pastoral region and hence, detached the link between hydro-climatic extremes and internal wars at the inter-annual time scale.

At the multi-decadal time scale, internal wars are associated with floods in all three agro-ecological regions. This may be attributable to the instantaneous onset of floods. Compared with droughts, the onset of floods is more immediate, making them quite difficult to guard against. Hence, the associated social impact is more drastic and immediate (Burton et al., 1993). On one hand, people can employ more mitigating measures for droughts at the longer time scale. For instance, in the pastoral region, pastoralists can migrate to suitable locations. In parallel, subject to the instantaneous onset of floods, relatively few measures are available to human societies in mitigating floods. On the other hand, land in flood plains is more fertile. This also attracts people to stay in flood plains and expose themselves to the risks of floods (Burton et al., 1993). Even if humans can modify the environment, it will only result in vicious cycles in the long-term. The flood hazard of the Yellow River is a typical example (Chen et al., 2012). Even though enormous manpower and resources have been spent in mitigating floods, agricultural production and social stability in the North China Plain is incessantly disturbed by the floods of the Yellow River. The above factors may explain why the multi-decadal variability of internal wars in the three agro-ecological regions in China is significantly determined by floods.

The multi-decadal (32–64 year) coherence between hydro-climatic extremes and internal wars may be brought by the multi-decadal variability of El Niño–Southern Oscillation (ENSO). It has been proved in some empirical paleo-climate studies that floods and droughts in China (including the agro-pastoral interlocking zone in northwestern China) are significantly driven by ENSO over the past millennium (Chen et al., 2015; Lee et al., 2015a, 2015c). The periodic cycles of ENSO are about two to seven years, in general. But, from the ENSO reconstruction over the last 700 years, multi-decadal variability of ENSO can also be observed (Li et al., 2013). When ENSO strengthens or weakens at the multi-decadal time scale, there will be significant changes in the frequency and spatial pattern of floods and droughts across China. This may subsequently modulate the spatio-temporal pattern of internal wars, resulting in the multi-decadal coherence (32–64 year) between hydro-climatic extremes and internal wars.

4.2 Temporal variation

The multi-decadal coherence between hydro-climatic extremes and internal wars in all three agro-ecological regions is only significant in certain periods, implying their relationship to be non-linear and non-stationary in nature. Regarding the issue why the multi-decadal coherence between hydro-climatic extremes and internal wars in all three agro-ecological regions is only significant in certain periods, clues can be traced from the causal pathways from hydro-climatic extremes to internal wars in China as follows: Hydro-climatic extremes→agricultural shrinkage→population pressure→internal wars (Lee and Zhang, 2010b). As per population pressure, it is co-determined by agricultural production and population size (Lee and Zhang, 2013; Lee, 2014). It can be further deduced that the influence of hydro-climatic extremes on human societies is significant only when population size has reached a certain level (Lee and Zhang, 2010a). Therefore, the period of significant multi-decadal coherence identified by MWC (see Figure 3a–c) is compared with the population density in the three agro-ecological zones in China (Figure 4a–c). The general

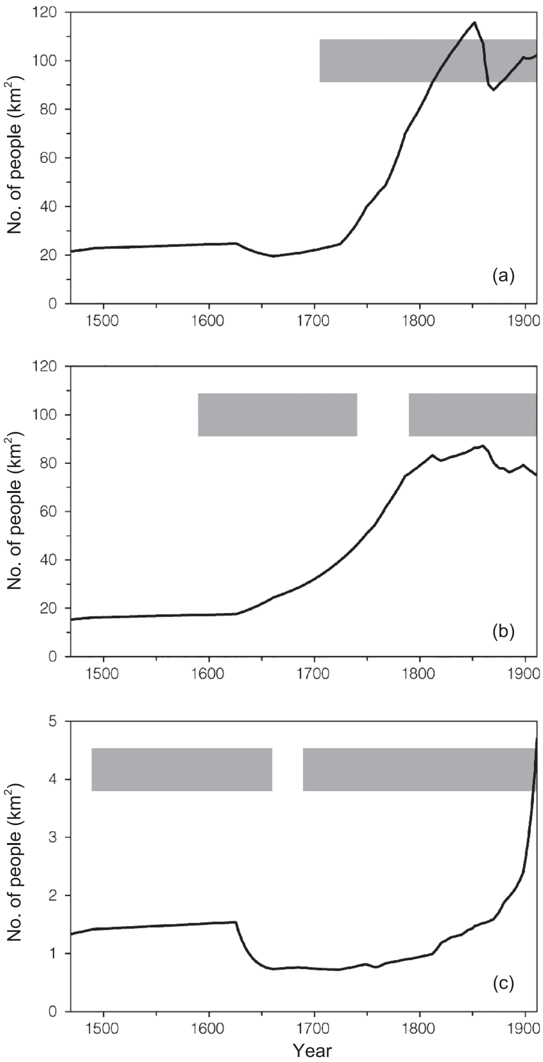

Figure 4 Comparison between the period of significant multi-decadal coherence identified by MWC (gray horizontal bar, cf. Figures 3a–c) and the population density (black curve) in the three agro-ecological regions in China. (a) Rice, (b) wheat, and (c) pastoral regions.

picture is that the coherence between hydro-climatic extremes and internal wars in different agro-ecological areas is significant when population density is increasing or at a relatively high level in relation to the regional carrying capacity. This is especially true since the 18th century, as population across China increased drastically. In the pastoral region, however, the break of 32–64 year coherence in AD1640–1710 is coincident with the trough of population density there (Figure 4c). This may further evidence the multi-decadal coherence between hydro-climate extremes and internal wars to be mediated by regional population pressure.

Another point should be made about the break of 32–64 year coherence in the wheat region in AD1720–1810 (Figure 4b). The population density there is increasing rapidly during this time, while the timing of the coherence break seems to contradict with the role of population densityin mediating the coherence. Yet, the break may be attributable to the tremendous increase of subsistence brought about by land reclamation policy and the introduction of foreign food crops in northwestern China in the 18th century, which provisionally provides extra capacity to the wheat region in buffering the impact brought by hydro-climatic extremes (Lee et al., 2016b). Therefore, the link between hydro-climatic extremes and internal wars is detached. Yet, the coherence resumes in the early 19th century, when the extra capacity is depleted by population growth and unsustainable agricultural practices (Lee et al., 2016b). Perhaps the coherence break in the wheat region should be treated as an exceptional case.

4.3 Theoretical contribution and the importance of data disaggregation

Wars often have been compared with temperature and precipitation in previous large-N studies (cf. Section 1), while the detrimental effect of hydro-climatic extremes on wars is usually verified by regional studies, dynastic histories, and case studies (Ye et al., 2004; Jin, 2012; Liu et al., 2012; Cheng, 2015; Li Y P et al., 2017). The associated verification is rather qualitative, while the large-N quantitative analyses of the detrimental effect of hydro-climatic extremes on wars are quite insufficient (Zhang et al., 2010; Jia, 2014). In this study, we evidenced hydro-climatic extremes as significant drivers of internal wars in Chinese history via the use of big data and quantitative methods. Our findings may have highlighted the necessity of taking hydro-climatic extremes into consideration when addressing the man-land relationship in historical China.

Some large-N studies indicate droughts to be more important than floods in causing rebellions in the agricultural region (i.e., the rice and the wheat regions in this study) (Jia, 2014) as well as the whole of China (Zhang et al., 2010), historically. In this study, we divide the whole of China into three agro-ecological regions, which are also examined separately. Subject to the significant difference of regional climate and physical environment among the three agro-ecological regions, we find that droughts are only significant in causing internal wars in the wheat region at the inter-annual time scale. At the multi-decadal time scale, floods are more important than droughts in driving internal wars in all of the agro-ecological regions. The discrepancy between the findings in this research and previous studies reveals the complexity of the climate-man relationship as well as the inapplicability of generalizing climate-war nexus across a large geographic domain. In addition, the regional and temporal disparity regarding the influence of climatic extremes on internal wars shown in this study suggests that contextual circumstances such as geographic (e.g., physical environmental setting) and demographic (e.g., population pressure) factors should be considered when examining the climate-war nexus (cf. Sections 4.1 and 4.2). The associated issue is about how the study area should be delineated and disaggregated when the climate-man relationship is investigated, which may significantly affect research outcomes (Lee et al., 2015b, 2016a, 2017). This can be seen from the comparison of findings between this and the previous studies (Zhang et al., 2010; Jia, 2014). Nevertheless, the above topics are somehow overlooked in previous research, as most of the related large-N studies are currently predominantly conducted on a national or macro-regional scale. This study preliminarily addresses those topics, which may serve as theoretical underpinnings for data disaggregation in future research.

5. Conclusion

We apply Poisson regression and wavelet transform coherence analyses to prove that floods and droughts are important factors in triggering internal wars in China in AD1470–1911. Yet, the relationship is characterized by strong regional variation. In the rice region, floods trigger internal wars at the inter-annual and multi-decadal time scales. In the wheat region, both droughts and floods cause internal wars at the inter-annual and multi-decadal time scales. In the pastoral region, internal wars are associated with floods only at the multi-decadal time scale. Furthermore, the multi-decadal coherence between hydro-climatic extremes and internal wars in all of the three agro-ecological regions is only significant in periods in which population density is increasing or the upper limit of regional carrying capacity is being reached. This study shows that climate-war nexus is significantly mediated by regional geographical factors (e.g., physical environmental setting and population pressure). In the temporal dimension, the climate-war nexus is non-linear and non-stationary. Subject to the multiplicity and complexity of the human-land relationship, researchers who study the historical climate-human nexus are recommended to boil down data according to geographic regions in the course of statistical analysis, with each of the regions examined individually. In that manner, the concern of "regional disparity" should be strengthened and internalized.

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